CERES Angular Distribution Model Working Group Report

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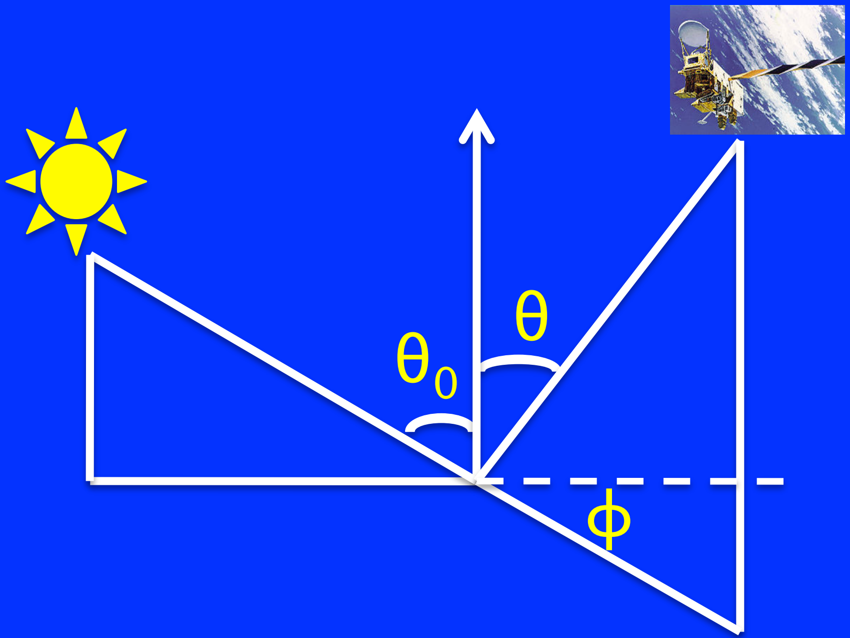
Outline

- Introduction of CERES angular distribution model and why it is important
- Compare matched radiances between Suomi-NPP and Aqua
- Quantify the uncertainties in Suomi-NPP fluxes inverted using Aqua ADMs using simulated Aqua and Suomi-NPP observations

From radiance to flux: angular distribution models

$$F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)}$$

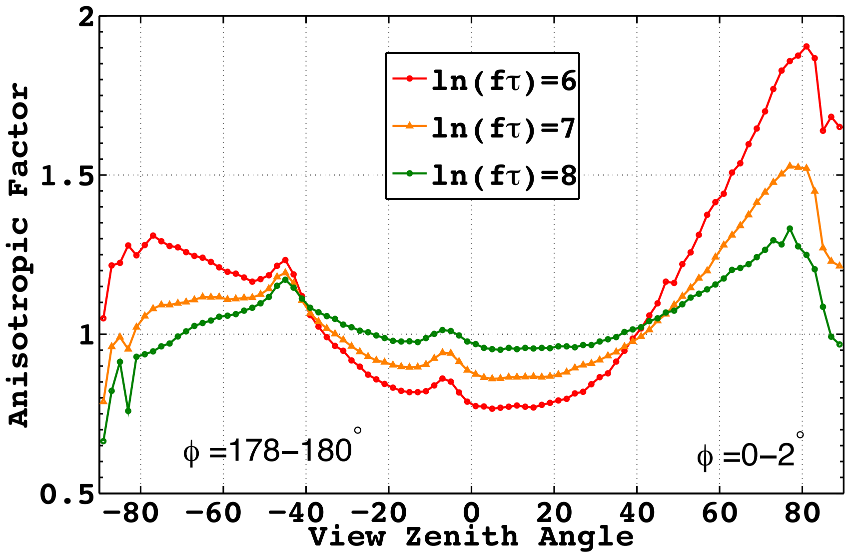
- Sort observed radiances into angular bins over different scene types;
- Integrate radiance over all θ and ϕ to estimate the anisotropic factor for each scene type;
- Apply anisotropic factor to observed radiance to derive TOA flux;



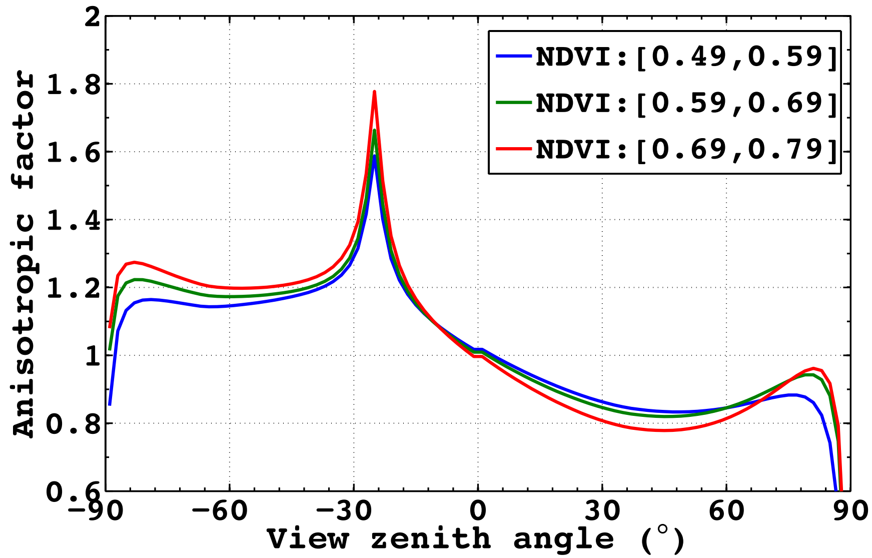
$$R(\theta_0, \theta, \phi) = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\int_0^{2\pi} \int_0^{\frac{\pi}{2}} \hat{I}(\theta_0, \theta, \phi) cos\theta sin\theta d\theta d\phi} = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)}$$

Examples of SW anisotropic factors

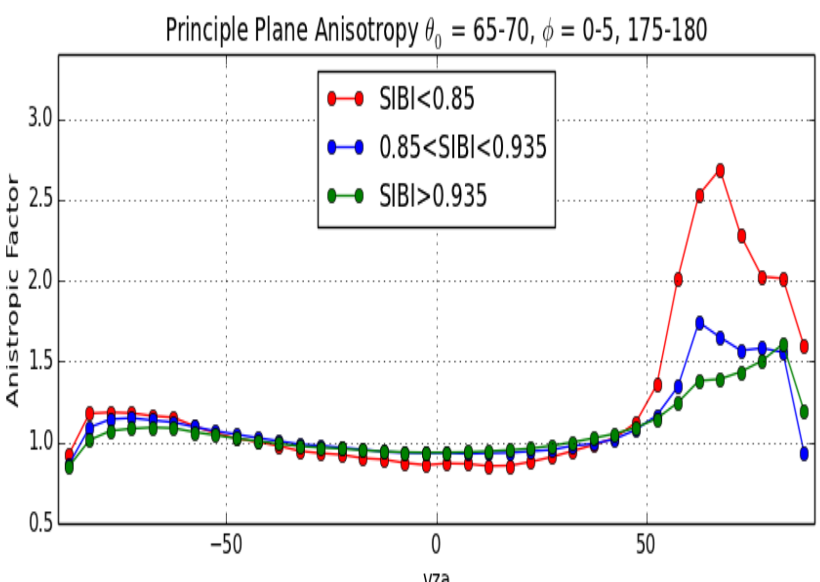
Liquid clouds over ocean at SZA=45



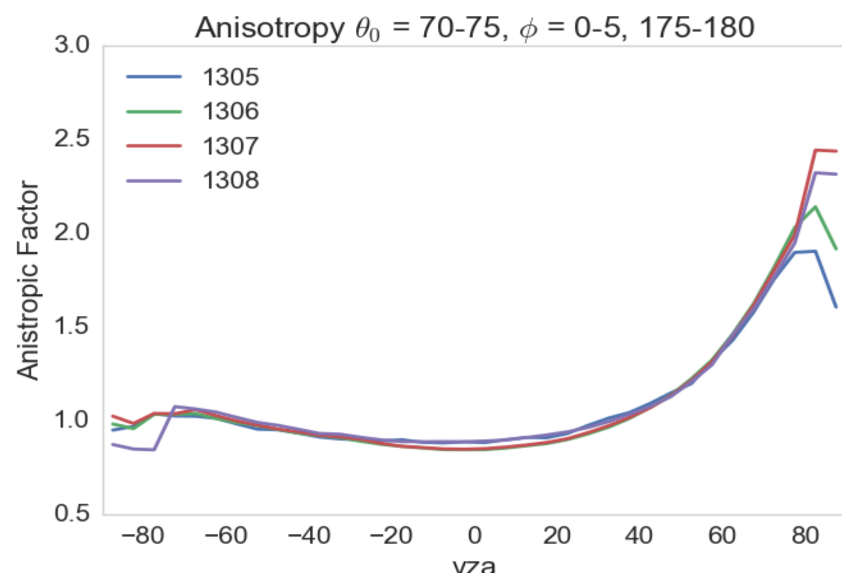
Clear land for July at SZA=24



Clear-sky sea ice for SZA=65-70

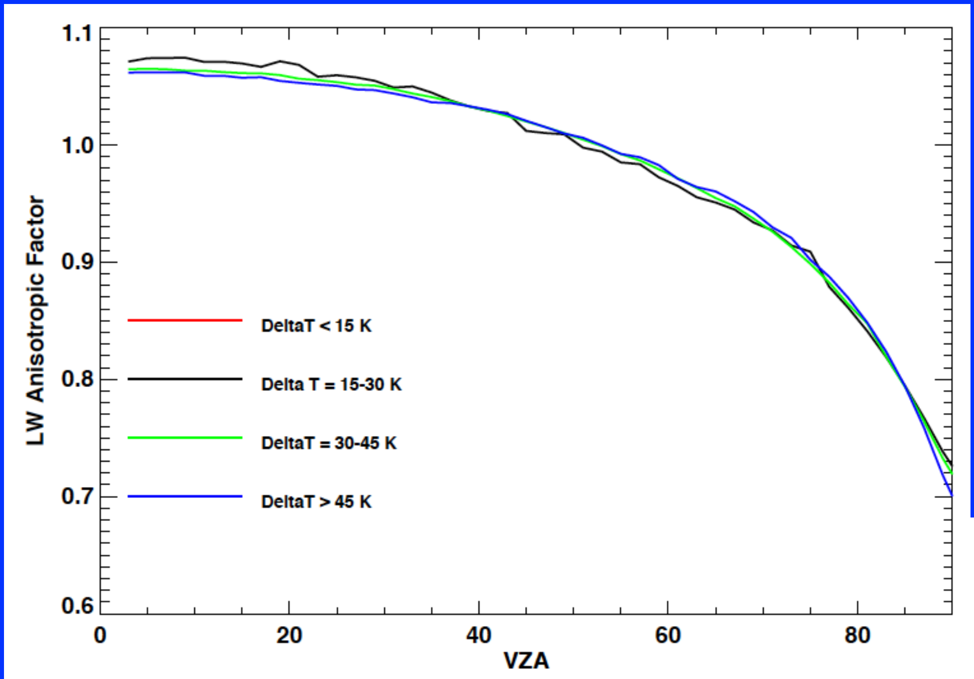


Overcast permanent snow for SZA=70-75

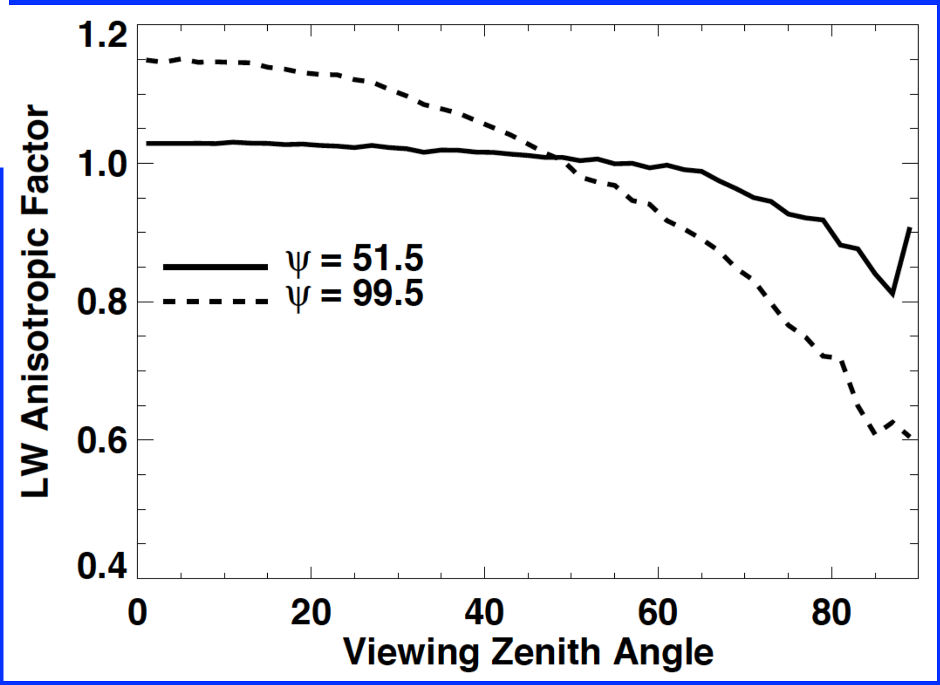


Examples of LW anisotropic factors

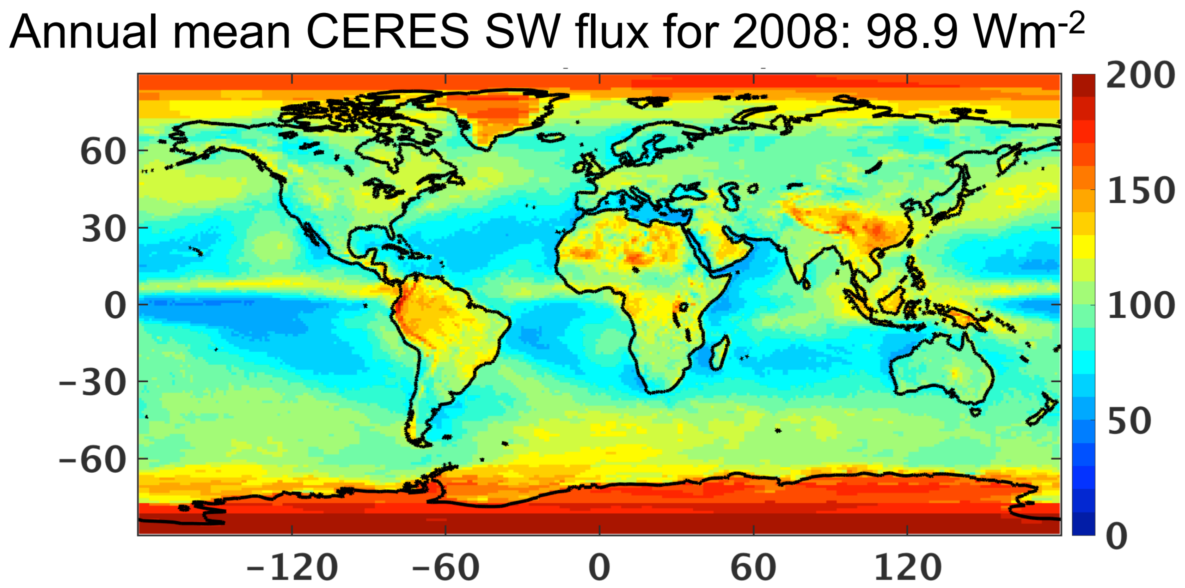
Clear dark desert for Ts=310-320, PW=1-3cm



Overcast over ocean: PW>5m, Ts=300-305, ΔT=65-70K

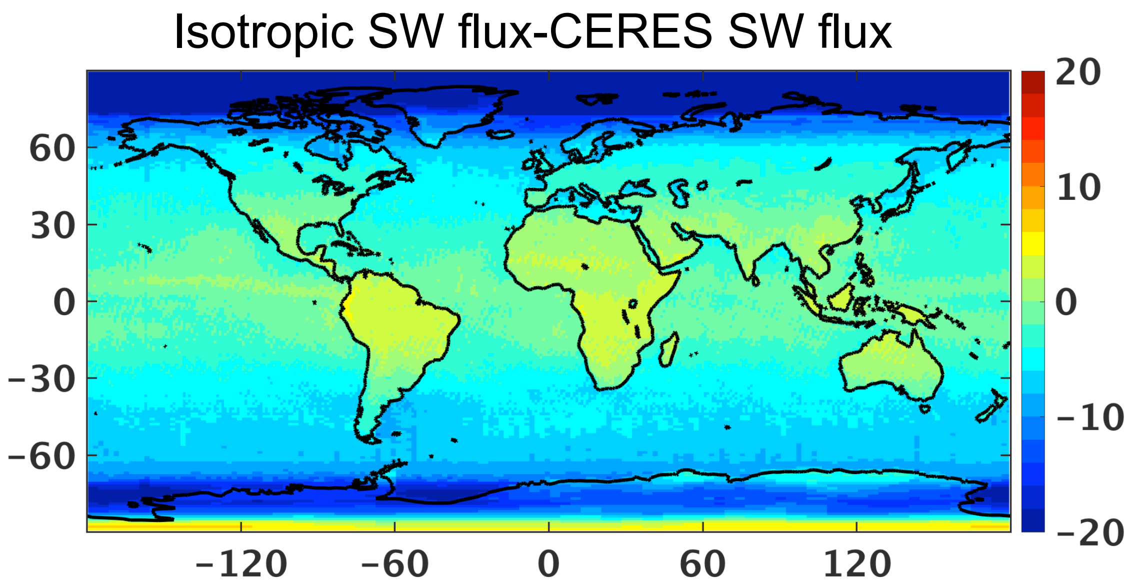


Effects of using isotropic assumptions on annual mean CERES SW fluxes

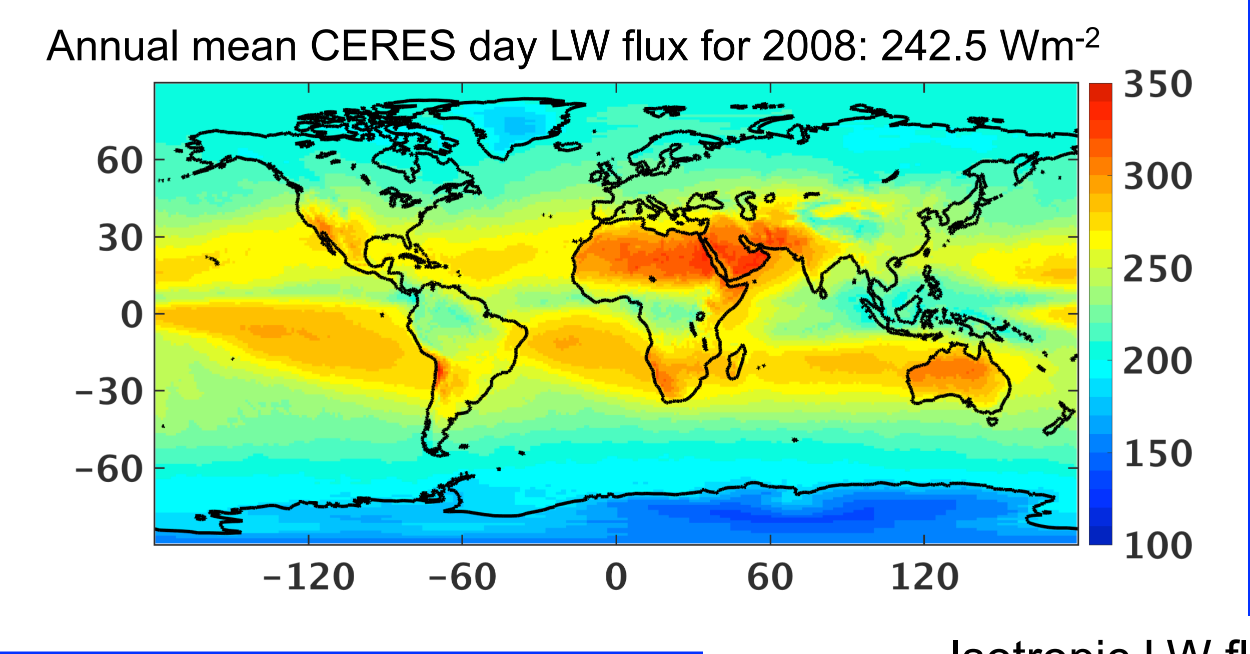


What if we use R=1 to replace the CERES empirical angular distribution models?

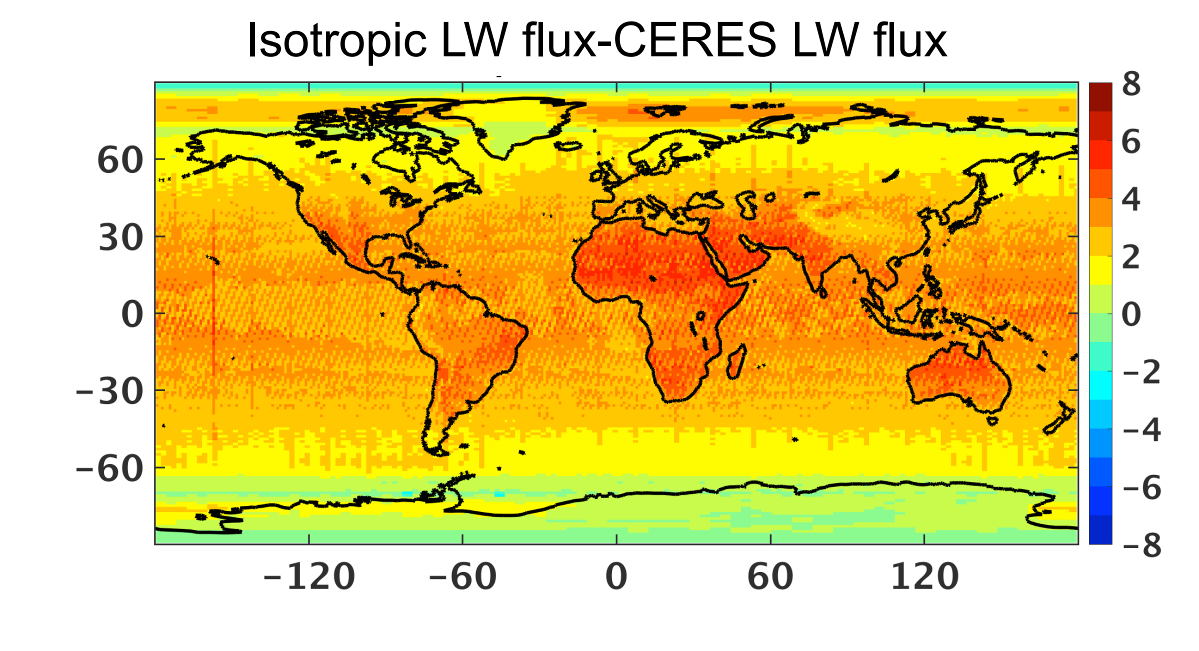
- Using isotropic assumption underestimates the global mean SW flux by 4.1 Wm-2.
- Regional differences can be up to 20 Wm-2.



Effects of using isotropic assumptions on annual mean CERES LW fluxes

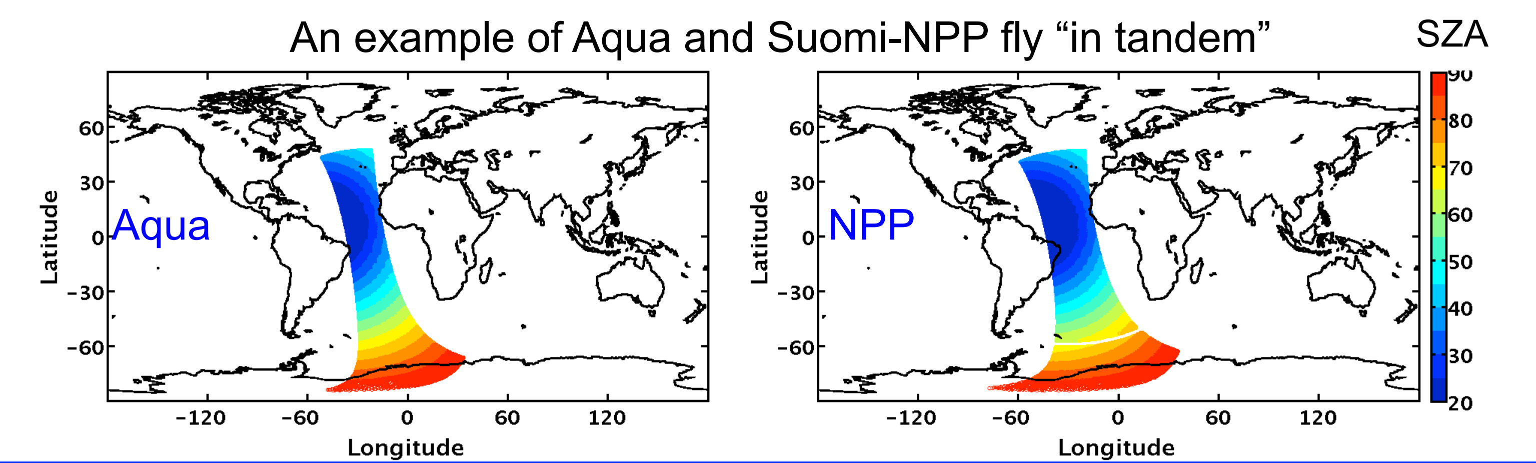


- Using isotropic assumption overestimates the global mean daytime LW flux by 2.8 Wm-2.
- Regional differences can be up to 6 Wm-2.

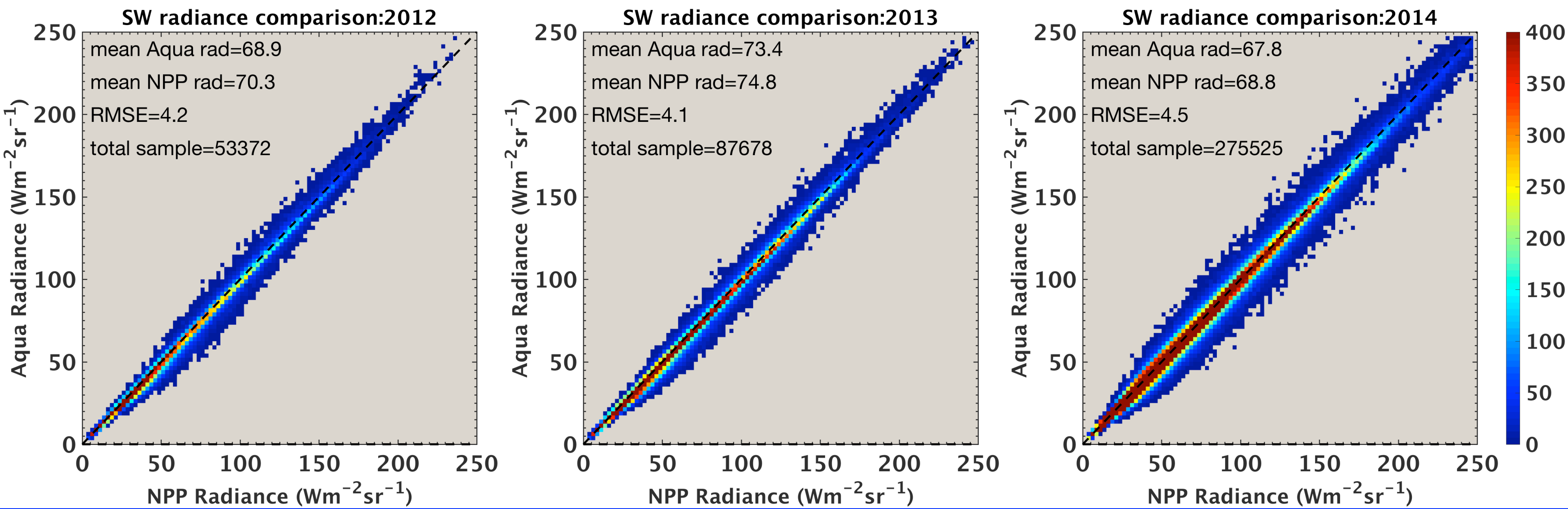


Radiance comparison using simultaneous observations

- About every 64 hours, Aqua and Suomi-NPP fly "in tandem".
- These simultaneous observations from Aqua and Suomi-NPP are matched to compare SW and LW radiances using CERES SSF data of 2012, 2013, and 2014.
- Matching criteria used for SW radiances are:
  - latitude and longitude differences are less than 0.05 degree, solar zenith angle difference is less than 2 degrees, viewing zenith angle and relative azimuth angle differences are less than 5 degrees.
- Matching criteria used for LW radiances are:
  - latitude and longitude differences are less than 0.05 degree, and viewing zenith angle difference is less than 2 degrees.

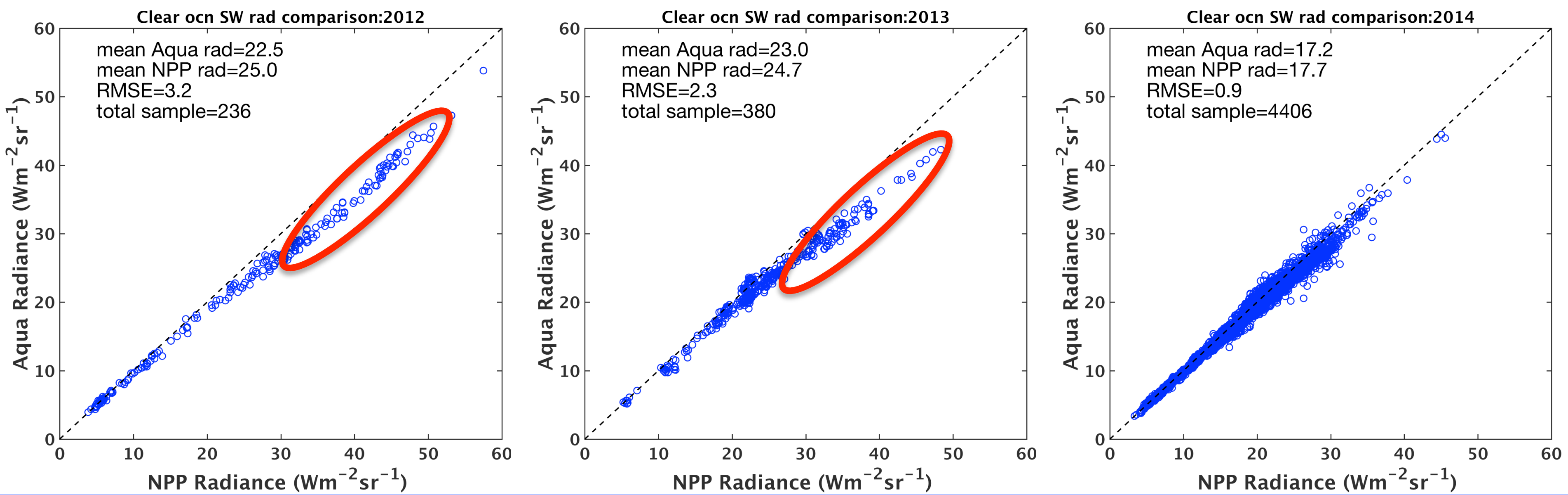


SW radiances between NPP and Aqua agree to within 2% @ footprint level



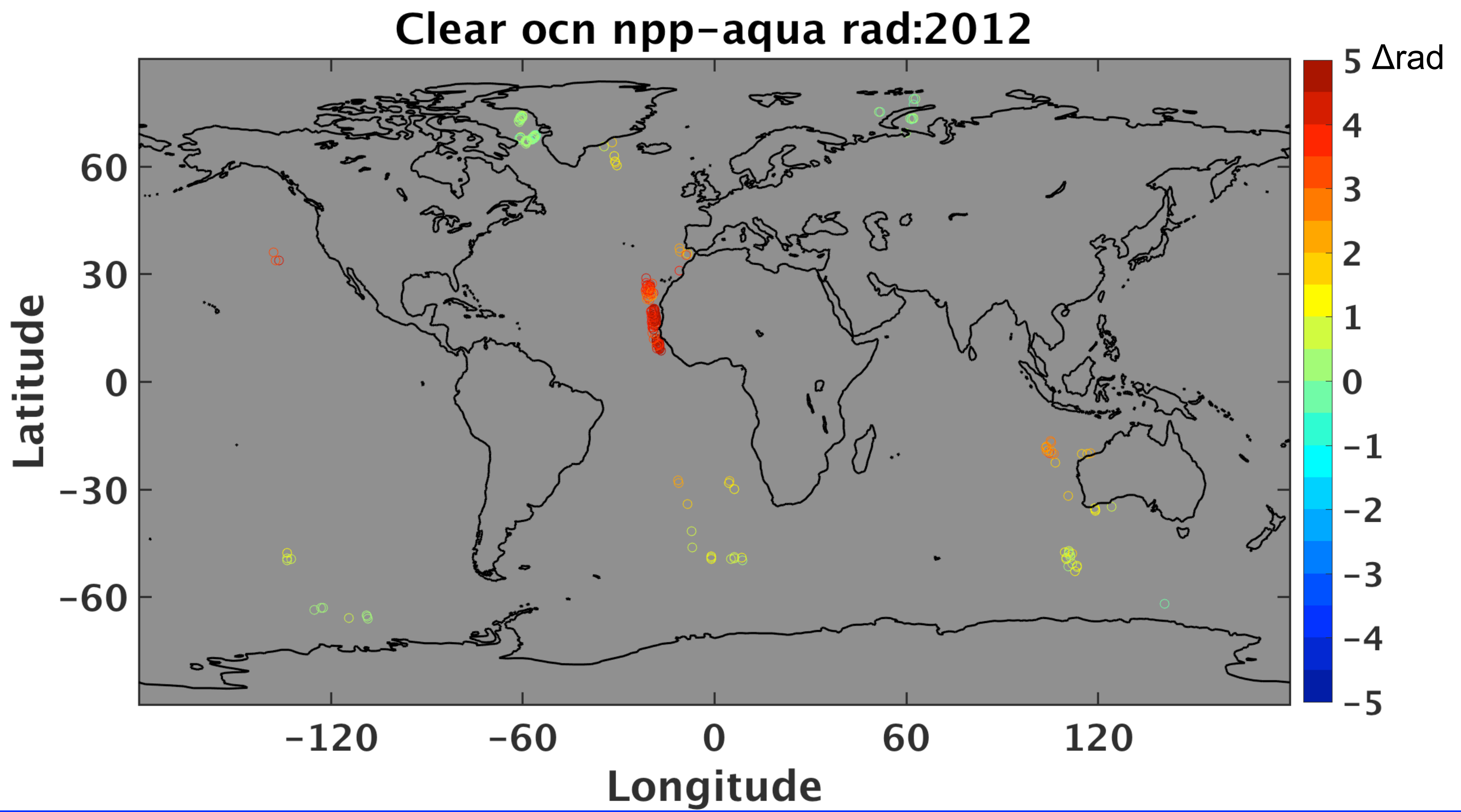
	N	Bias (Wm-2sr-1) NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE (Wm-2sr-1)
2012	53372	1.4	2.0%	4.2
2013	87678	1.4	1.9%	4.1
2014	275525	1.0	1.5%	4.5

SW radiances over clear ocean can diff by up to 11% !!!

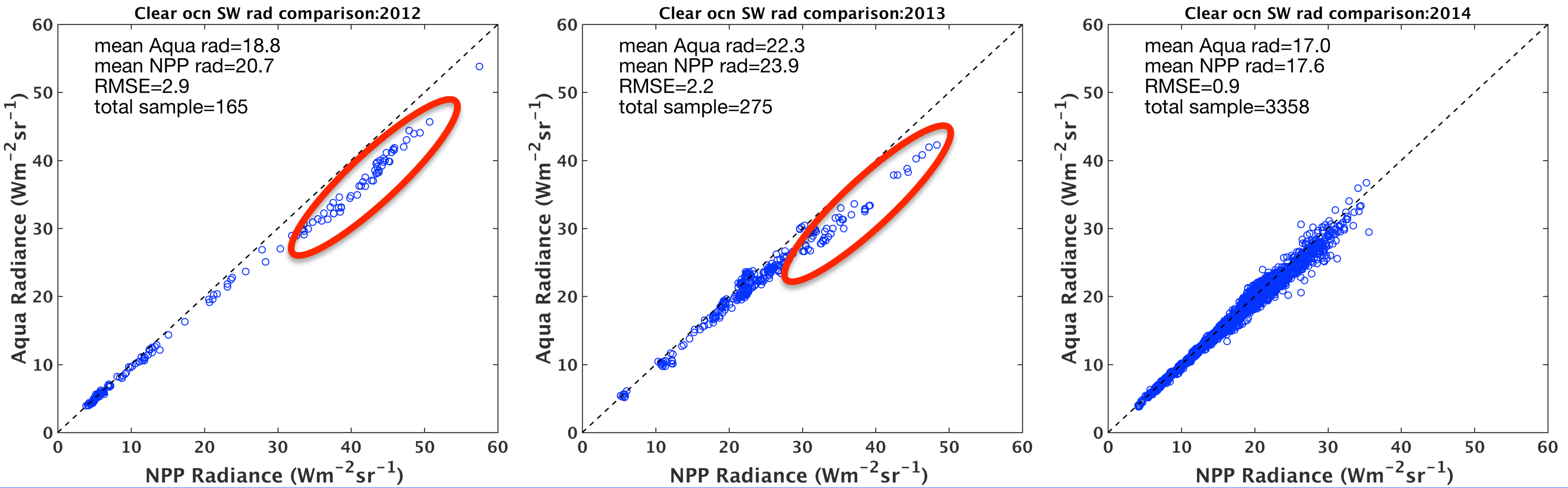


	N	Bias (Wm-2sr-1) NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE (Wm-2sr-1)
2012	236	2.5	11.1%	3.2
2013	380	1.7	7.4%	2.3
2014	4406	0.5	2.9%	0.9

Large biases are near coast, especially off the west coast of Sahara

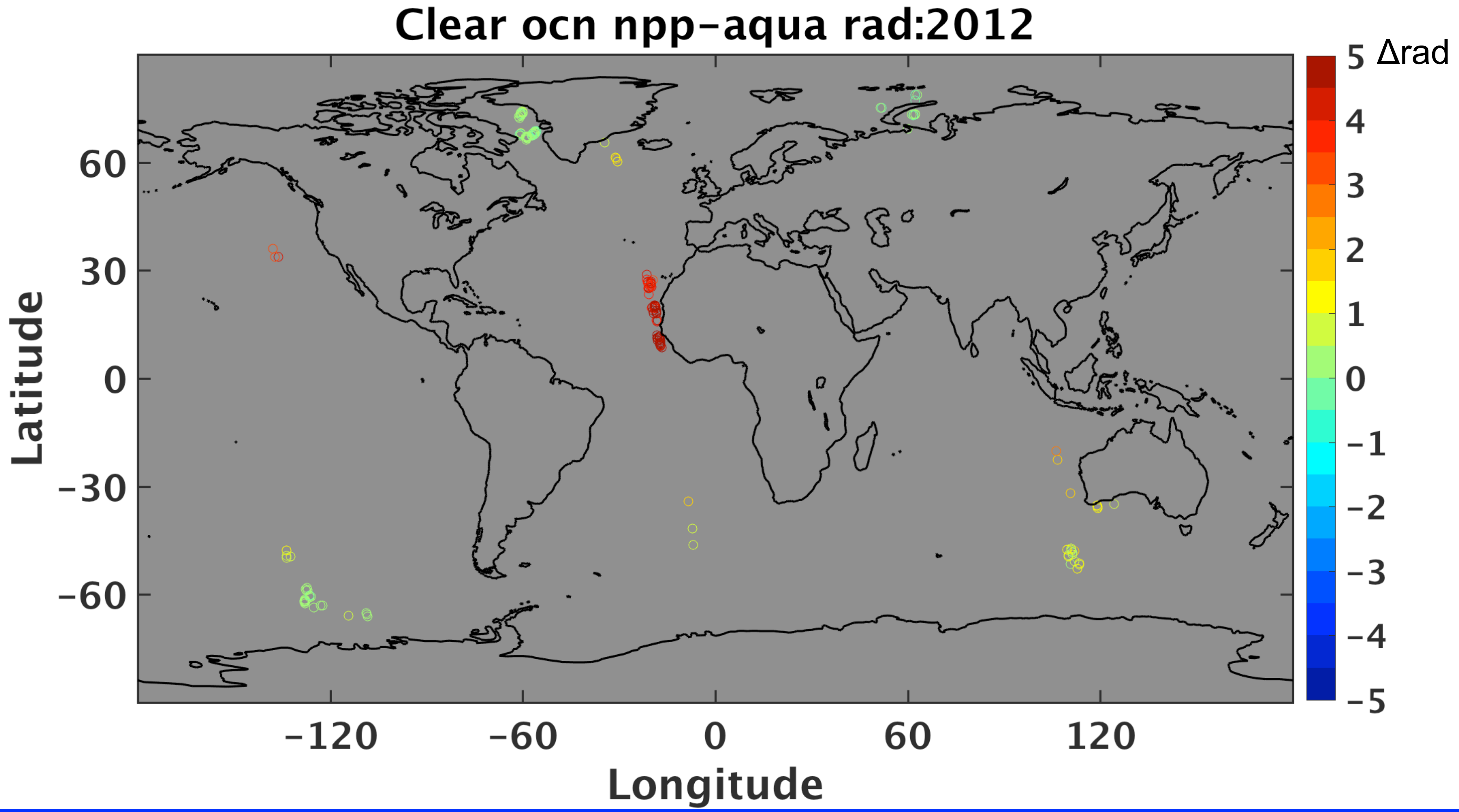


Exclude samples near coast: agreement improves a little bit

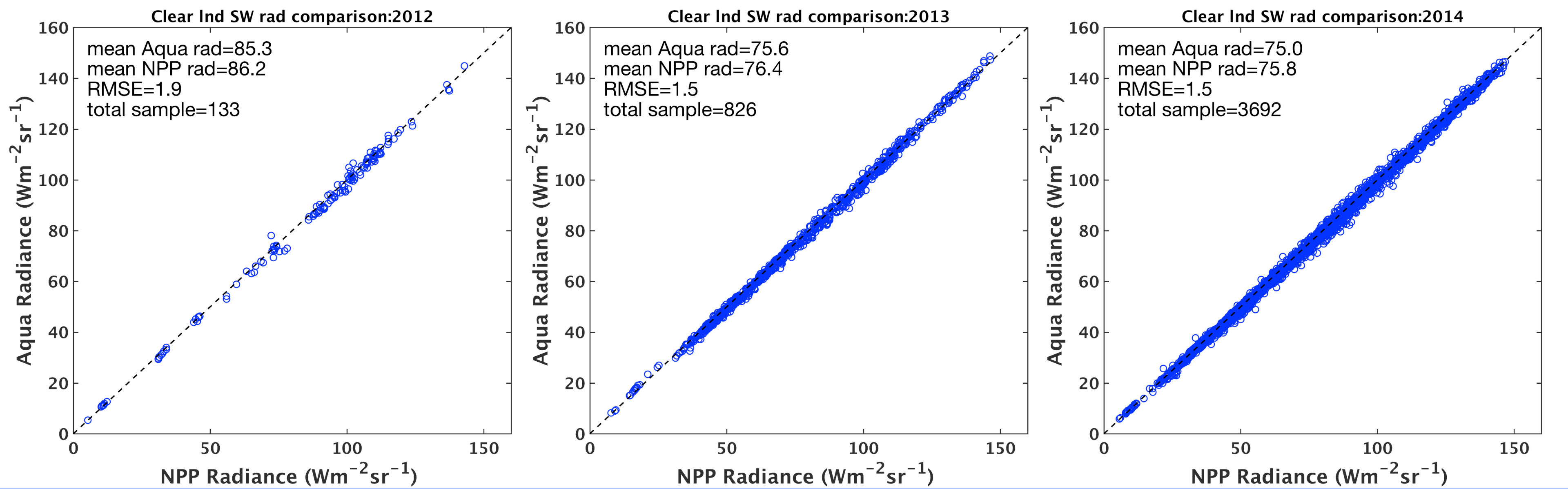


	N	Bias NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE
2012	165	1.9	10.1%	2.9
2013	275	1.6	7.2%	2.2
2014	3358	0.6	3.5%	0.9

Large biases off the west coast of Sahara

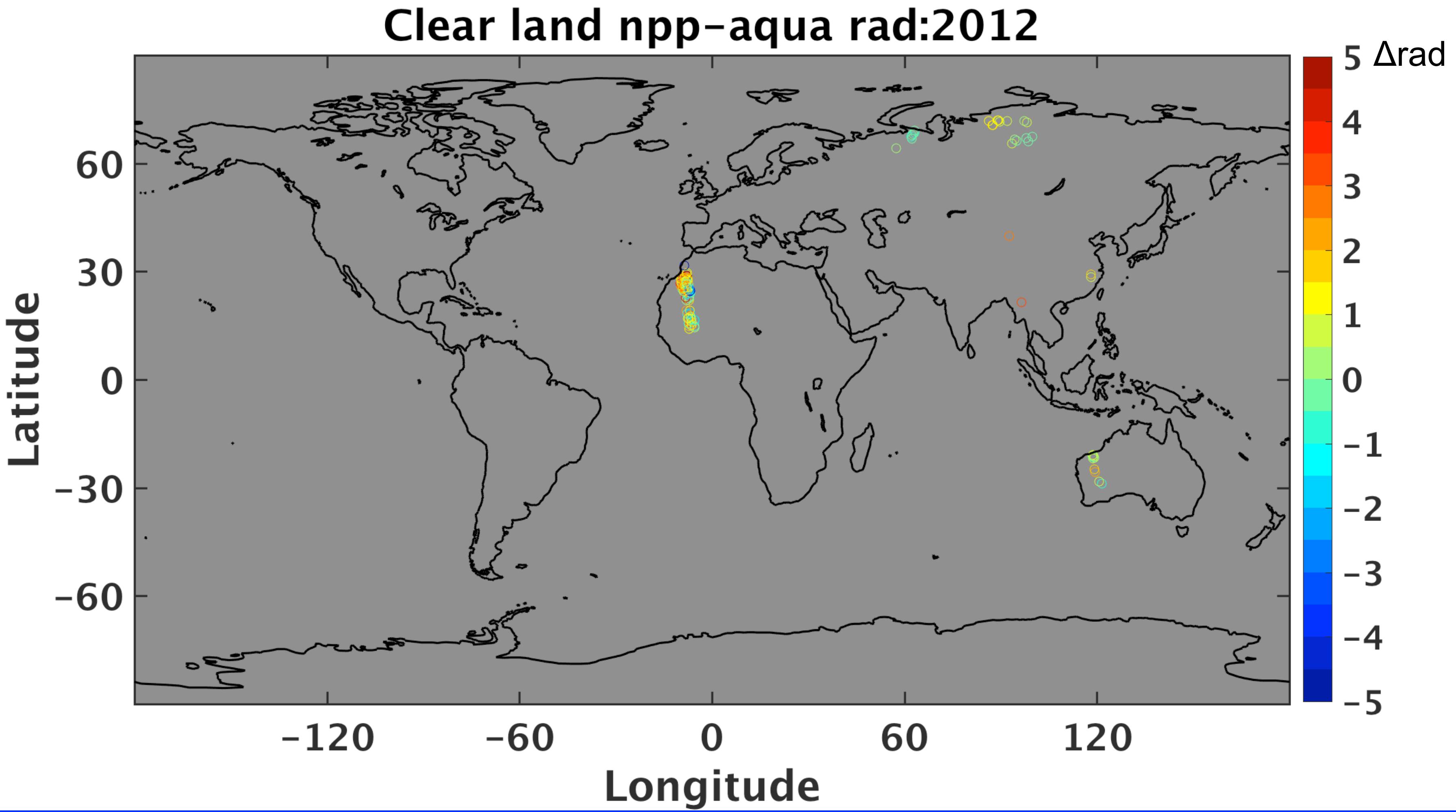


SW radiances over clear land agree to within ~1%

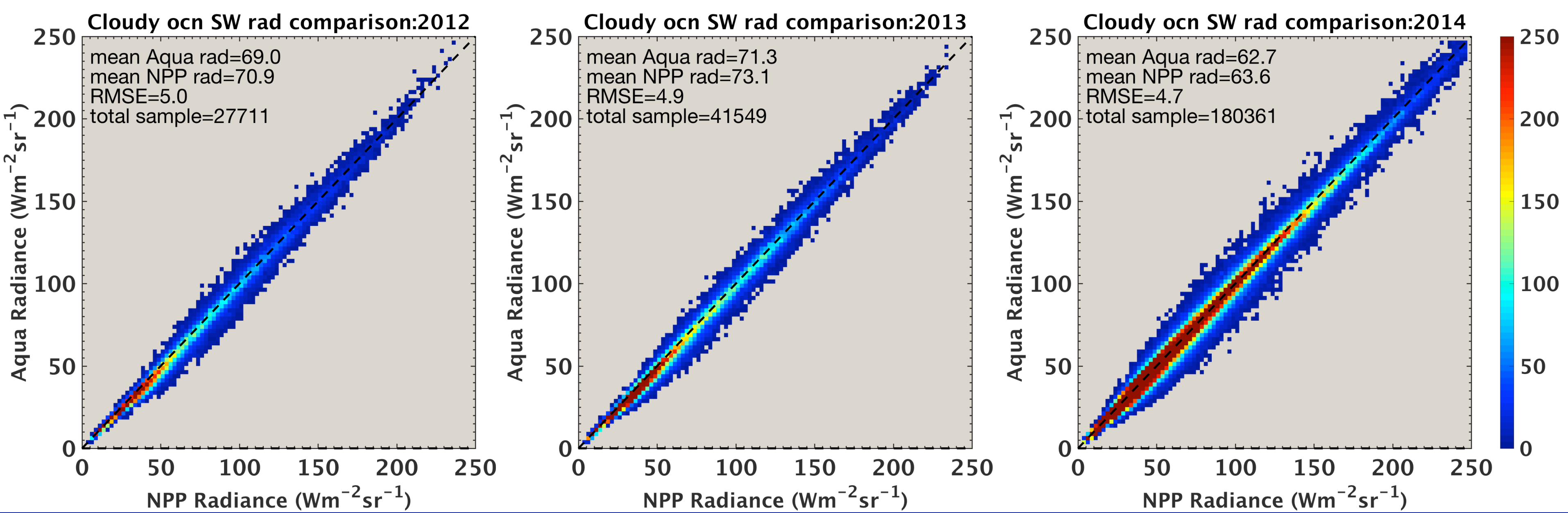


	N	Bias NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE
2012	133	0.9	1.1%	1.9
2013	826	0.8	1.1%	1.5
2014	3692	0.8	1.1%	1.5

SW radiance difference over clear land

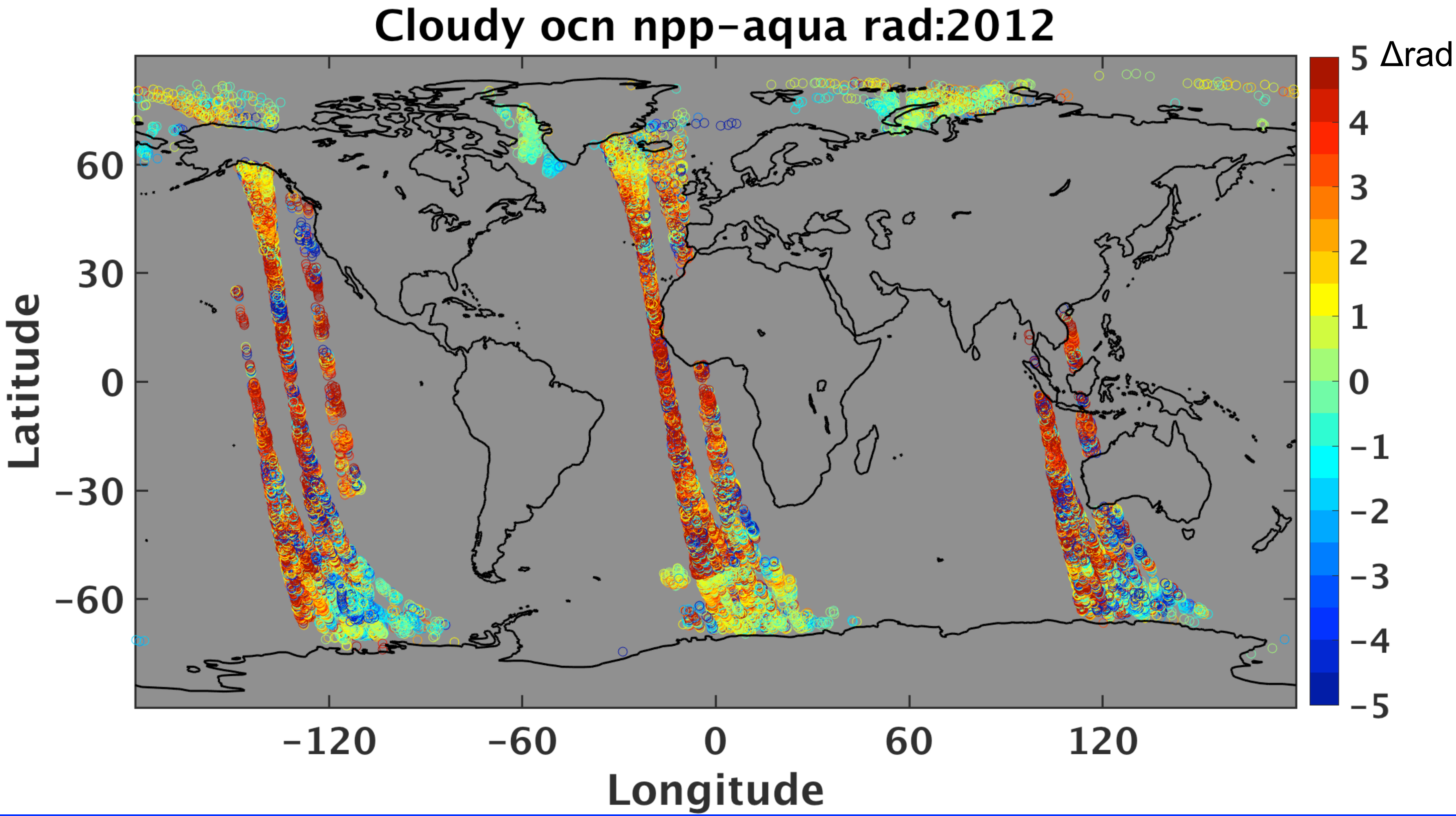


SW radiances over cloudy ocean agree to within 1.4% to 2.8%

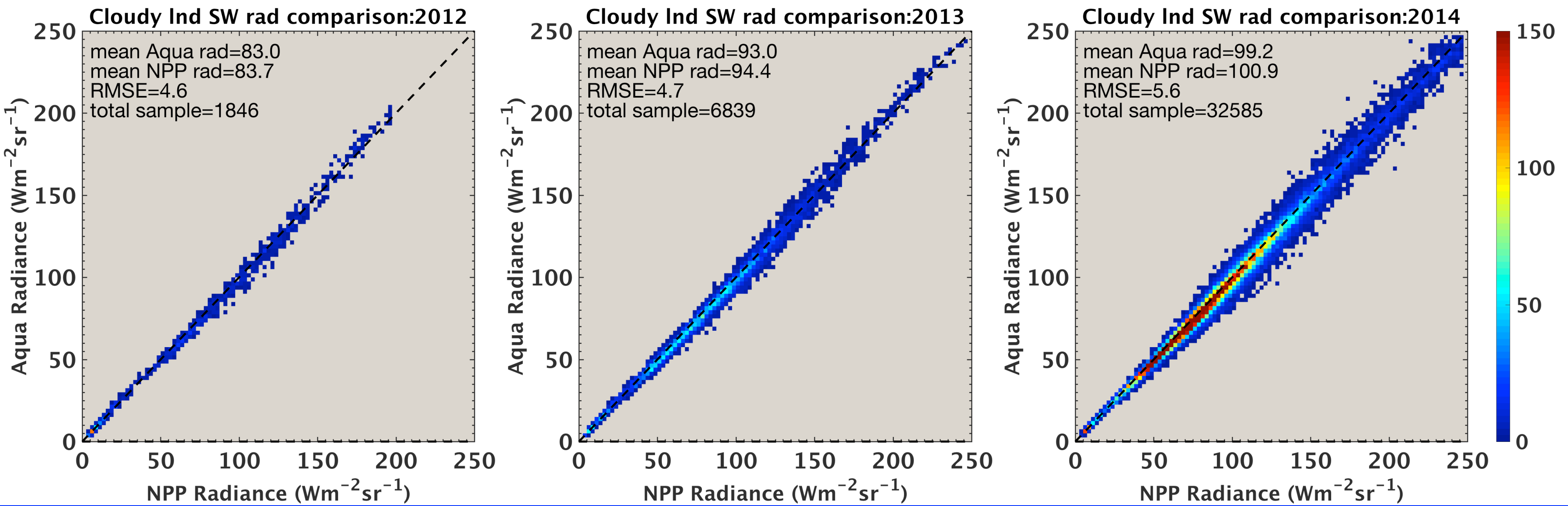


	N	Bias NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE
2012	27711	1.9	2.8%	5.0
2013	41549	1.8	2.5%	4.9
2014	180361	0.9	1.4%	4.7

SW radiance difference over cloudy ocean

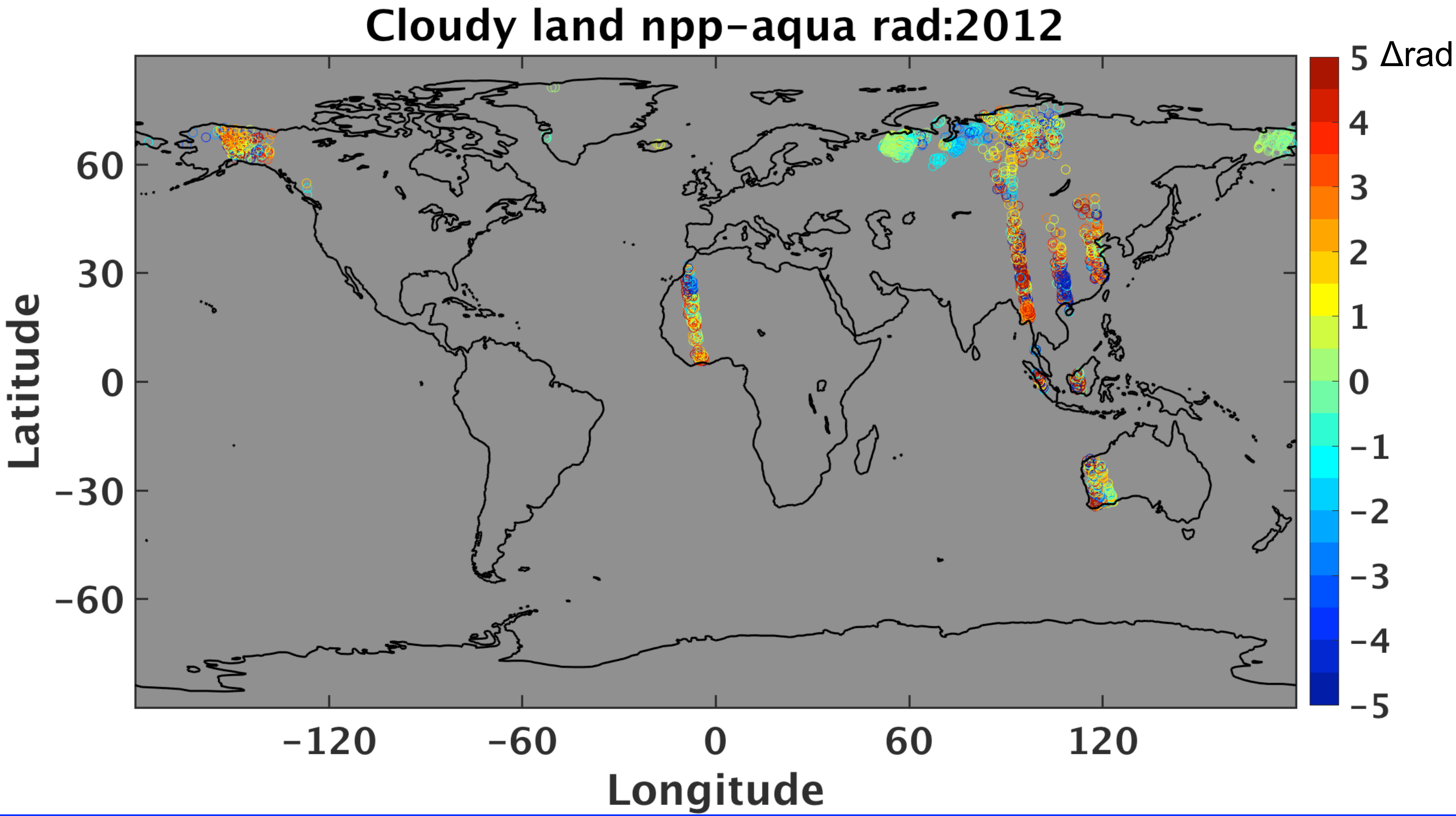


SW radiances over cloudy land agree to within 0.8% to 1.7%

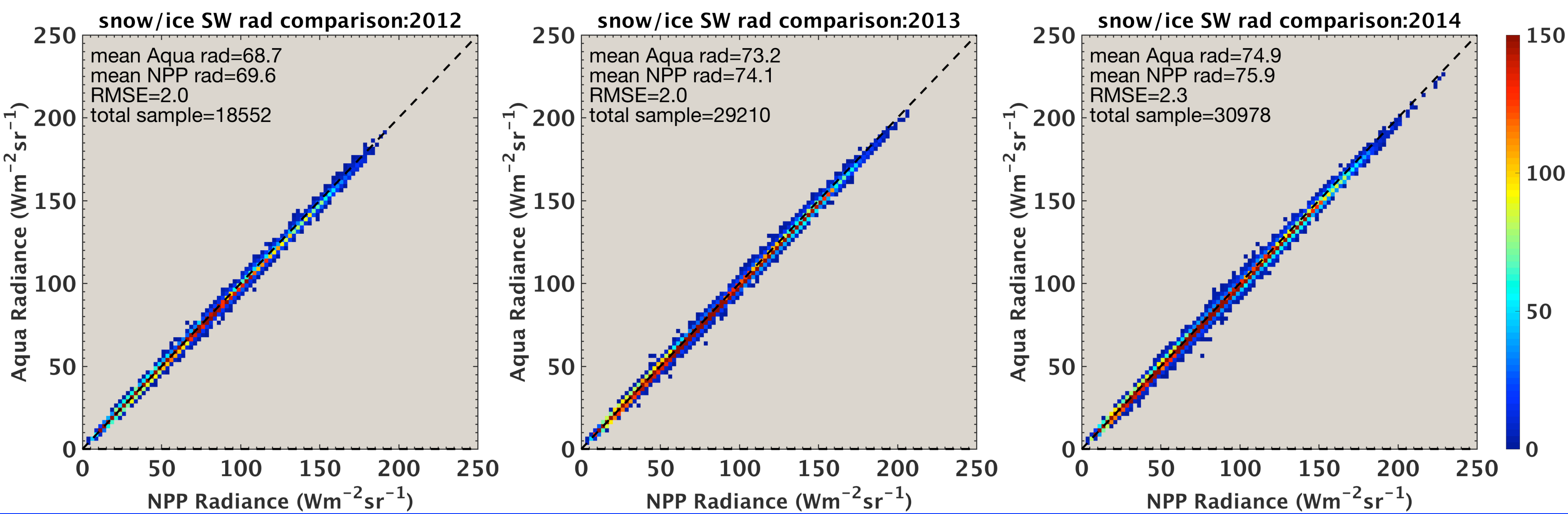


	N	Bias NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE
2012	1846	0.7	0.8%	4.6
2013	6839	1.4	1.5%	4.7
2014	32585	1.7	1.7%	5.6

SW radiance difference over cloudy land

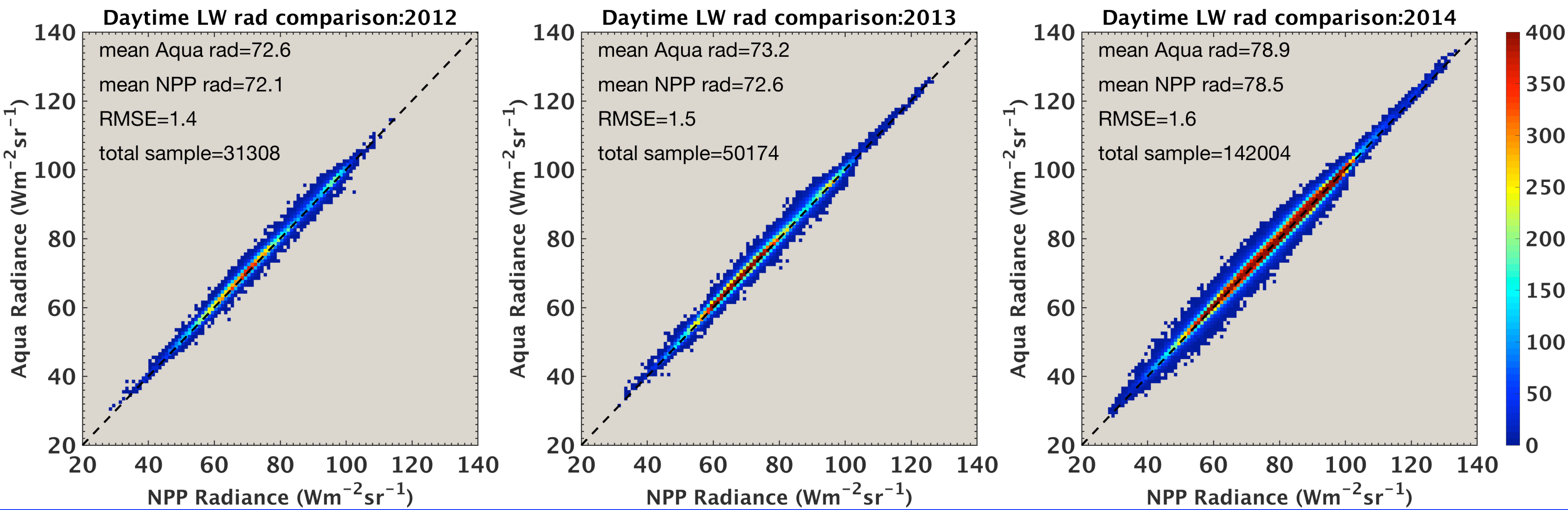


SW radiances over snow/ice agree to within 1.3%



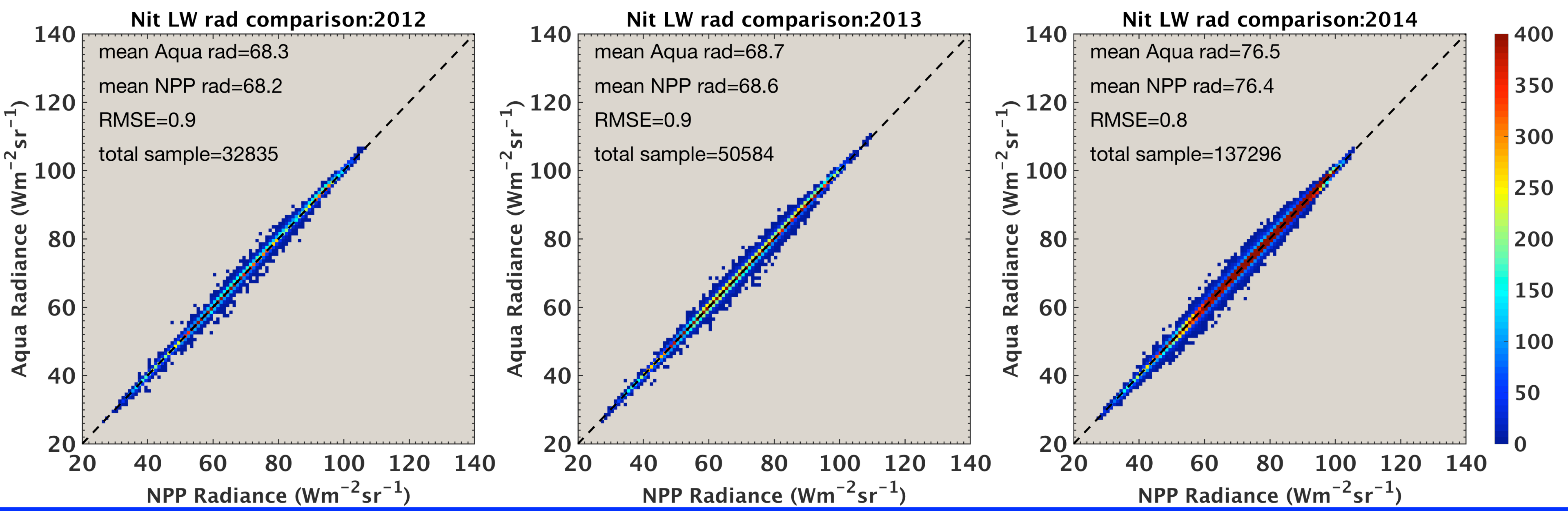
	N	Bias NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE
2012	18552	0.9	1.3%	2.0
2013	29210	0.9	1.2%	2.0
2014	30978	1.0	1.3%	2.3

Daytime LW radiances agree to within 0.8%



	N	Bias NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE
2012	31308	-0.5	-0.7%	1.4
2013	50174	-0.6	-0.8%	1.5
2014	142004	-0.4	-0.5%	1.6

Nighttime LW radiances agree to within 0.2%



	N	Bias NPP-Aqua	Rel bias (NPP-Aqua)/Aqua*100	RMSE
2012	32835	-0.1	-0.2%	0.9
2013	50584	-0.1	-0.2%	0.9
2014	137296	-0.1	-0.1%	0.8

Aqua and NPP radiance comparison discussion

- Nighttime LW radiances between Aqua and NPP agree to within 0.1 $Wm^{-2}sr^{-1}$.
  - Indicates good agreement between Aqua and NPP total channel?
- Daytime NPP LW radiances are lower than Aqua LW radiances by 0.4-0.6 $Wm^{-2}sr^{-1}$, and NPP SW radiances are higher than Aqua SW radiances by 1.0-1.4 $Wm^{-2}sr^{-1}$.
  - LW radiance is determined as the difference between total channel and SW channel, does this mean the SW channel is responsible for most of the difference?
- SW radiance differences between NPP and Aqua show some dependence on scene types:
  - Larger difference over ocean than over land/snow/ice, is this caused by spectral response function and/or unfiltering process?

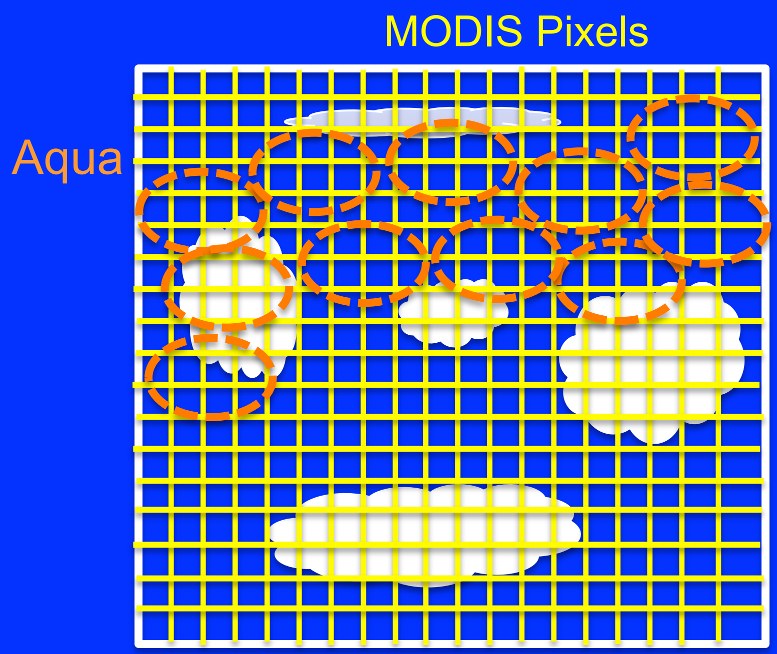
Quantify Suomi-NPP flux error caused by using Aqua ADMs

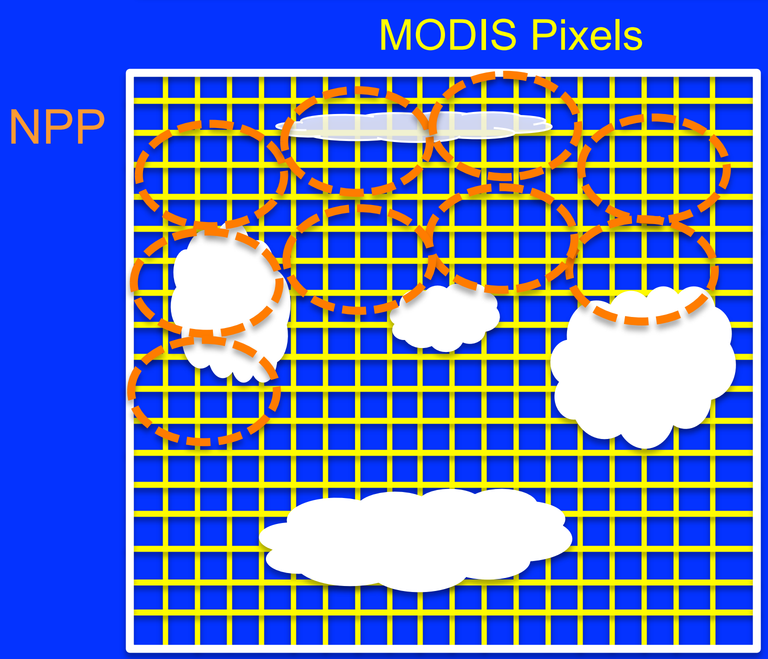
- Footprint size for S-NPP is larger than that for Aqua.
- Cloud properties retrieved from VIIRS can also be different from those retrieved from MODIS.

	Aqua	S-NPP
Launch	May 4, 2002	Oct. 28, 2011
Altitude	705 km	824 km
Inclination	98.14°	98.75°
Period	98.4 min	101.4 min

- How do these differences affect the S-NPP fluxes inverted using Aqua ADMs ?

Simulate Aqua and NPP footprints to quantify flux error due to different footprint sizes





- Derive broadband radiances for these simulated Aqua and NPP footprints using MODIS spectral channels:

$$I_{sw}^{md} = d_0 + \sum_{j=1}^{7} d_j I_j$$

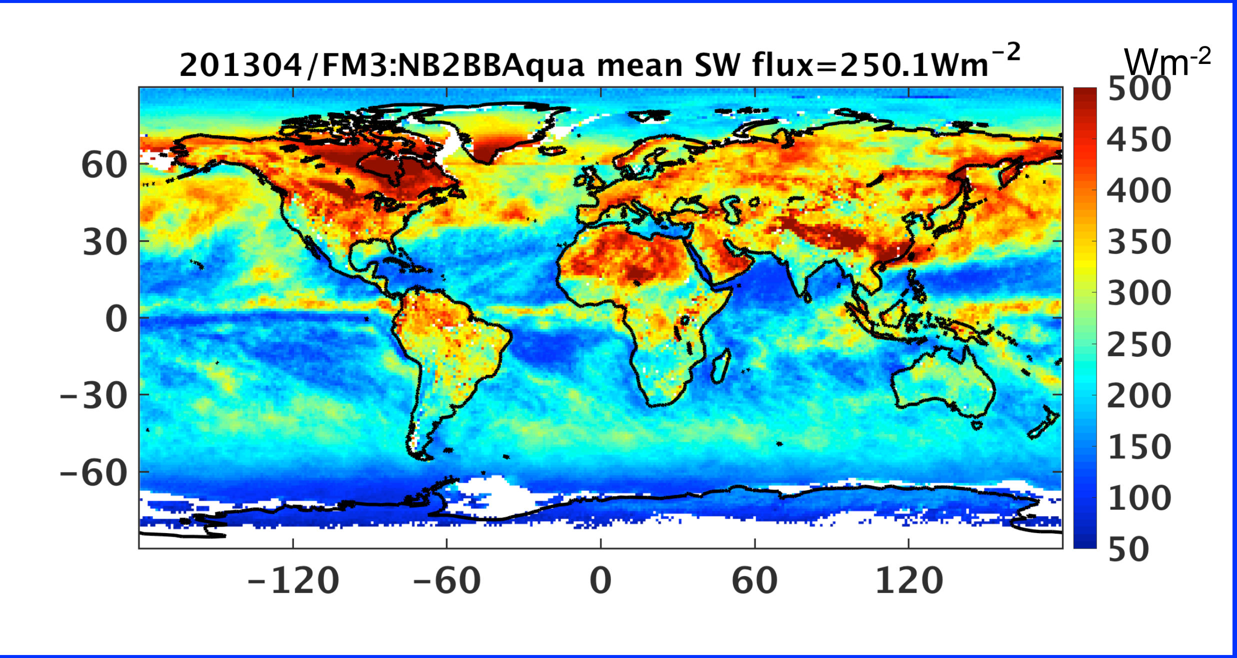
$$I_{lw}^{md} = a_0 + \sum_{j=1}^{5} a_j I_j$$

- Convert the broadband radiances to fluxes using Aqua ADMs and scene identification from MODIS

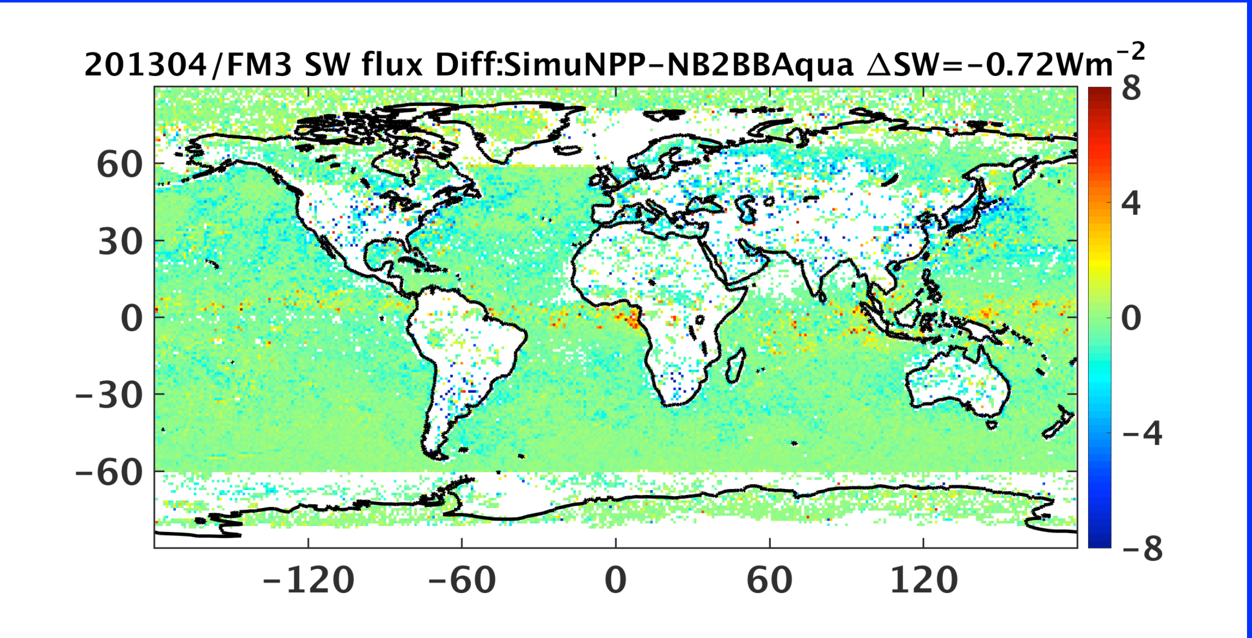
Develop narrowband-to-broadband (NB2BB) coefficients

- Use Aqua data from July 2002 to September 2007
- Shortwave
  - Use 7 MODIS spectral bands (0.47, 0.55, 0.65, 0.86, 1.24, 2.13 and 3.7 μm) in the regression
  - Derive monthly coefficients for discrete intervals of solar zenith angle, viewing zenith angle, relative azimuth angle, surface type, snow/non-snow, cloud fraction, cloud optical depth
- Longwave
  - Use 5 MODIS spectral bands (6.7, 8.5, 11.0, 12.1 and 14.2 μm)
  - Derive monthly coefficients for discrete intervals of viewing zenith angle, precipitable water, surface type, snow/non-snow, cloud fraction, cloud optical depth

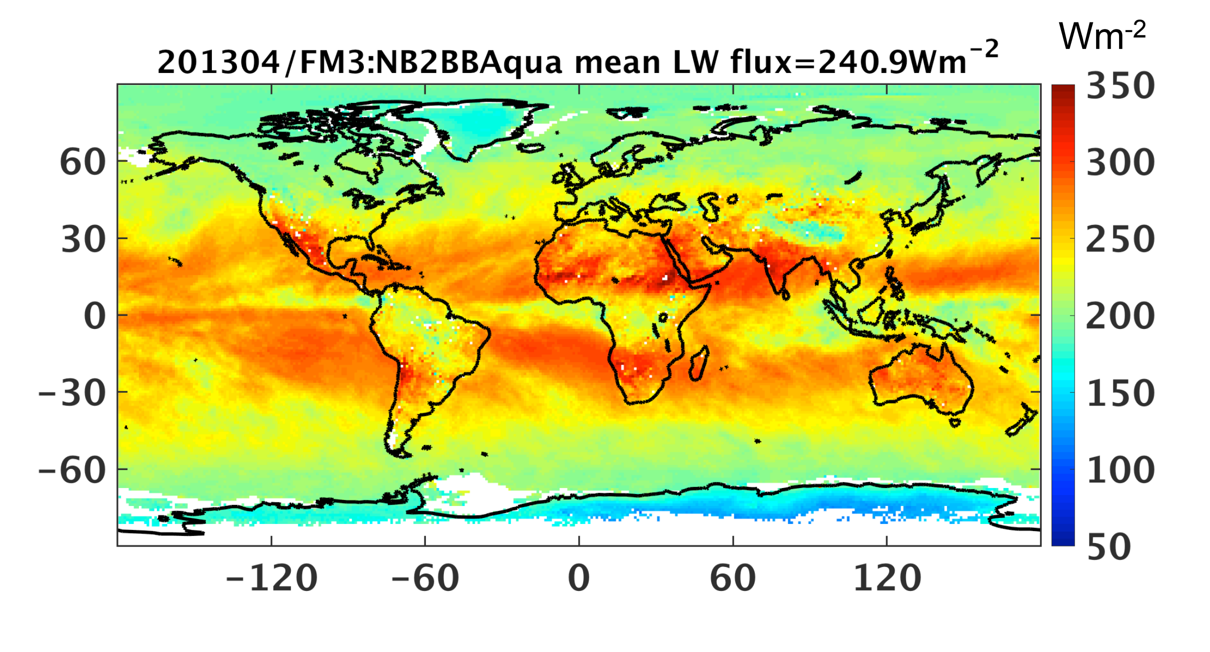
SW flux inverted from NB2BB radiance for Aqua footprint



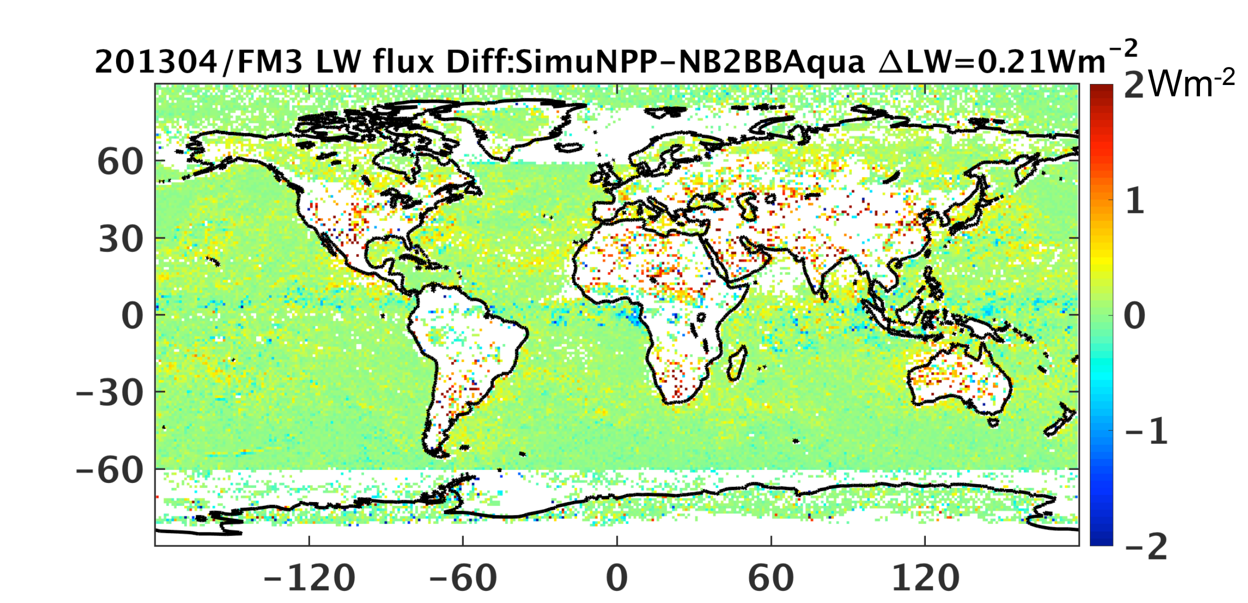
Change to NPP footprint size leads to SW flux difference of 0.7 Wm^{-2}



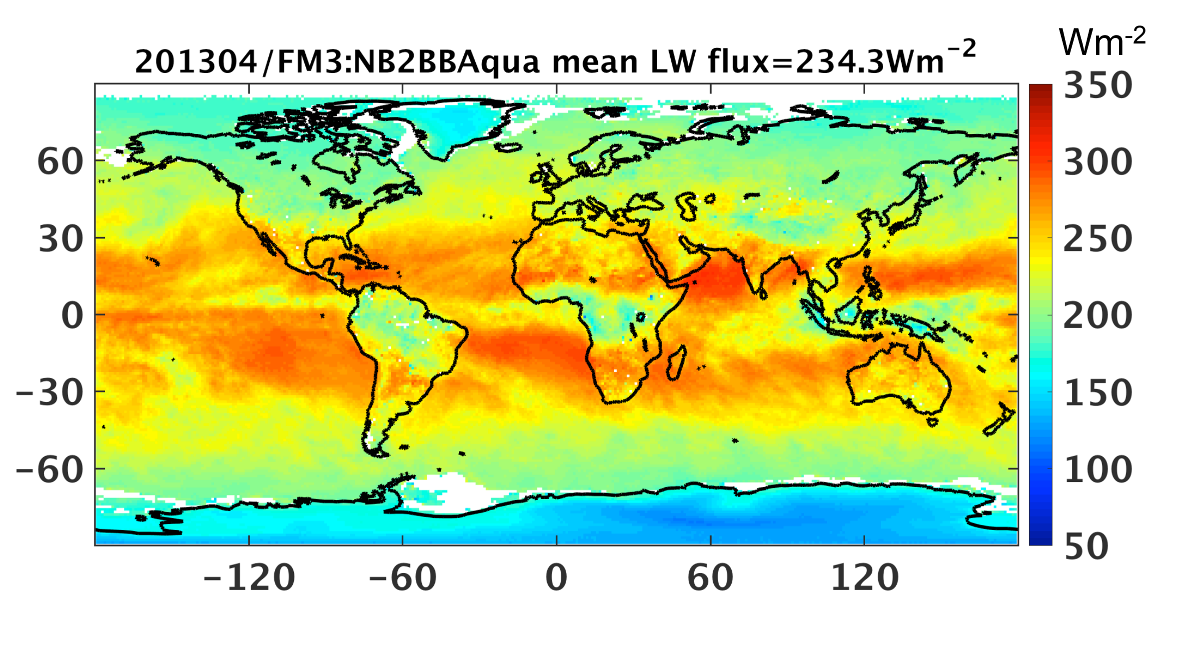
Daytime LW flux inverted from NB2BB radiance for Aqua footprint



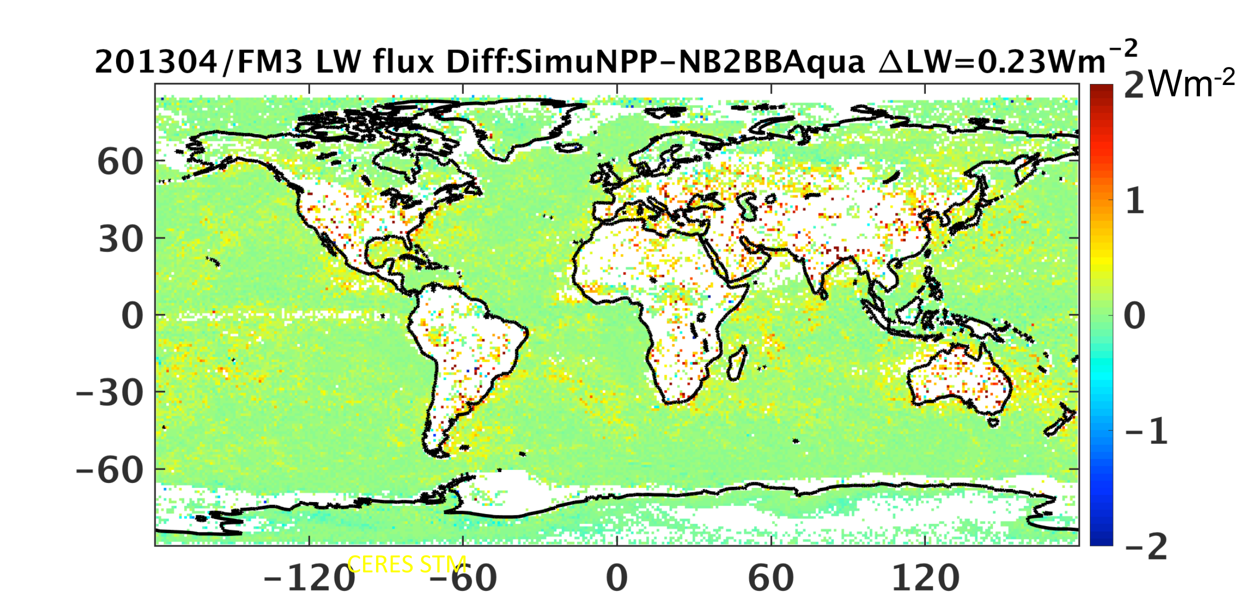
Change to NPP footprint size leads to daytime LW flux difference of 0.2 Wm^{-2}



Nighttime LW flux inverted from NB2BB radiance for Aqua footprint



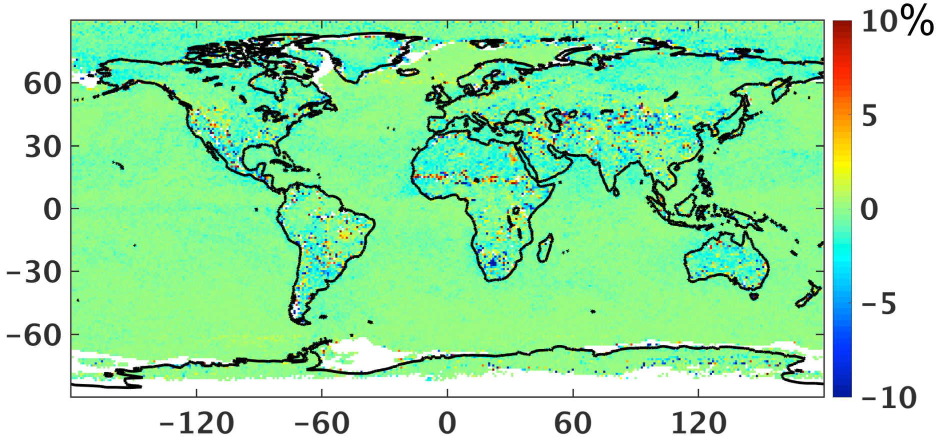
Change to NPP footprint size leads to nighttime LW flux difference of 0.2 Wm^{-2}



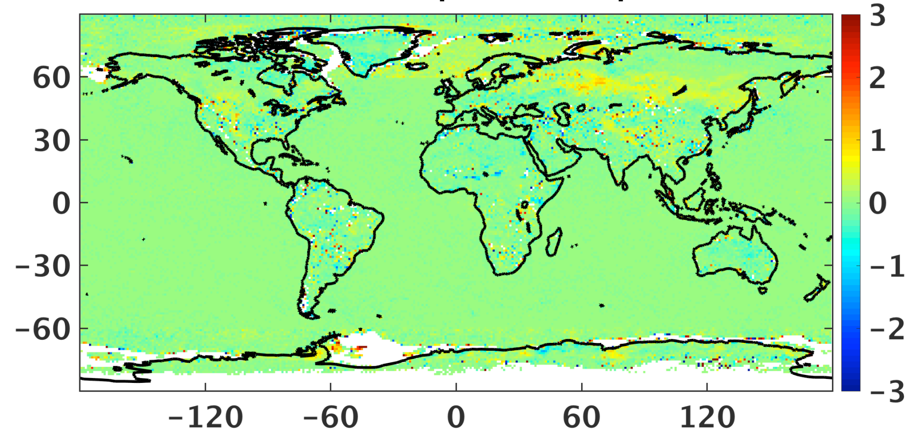
Simulated NPP footprints have almost identical cloud properties as Aqua

Simulated NPP-Aqua: April 2013

Cloud fraction

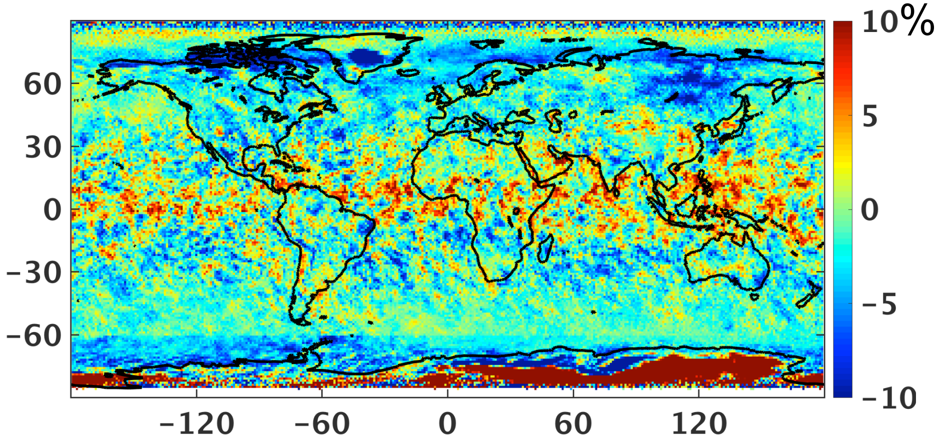


Cloud optical depth

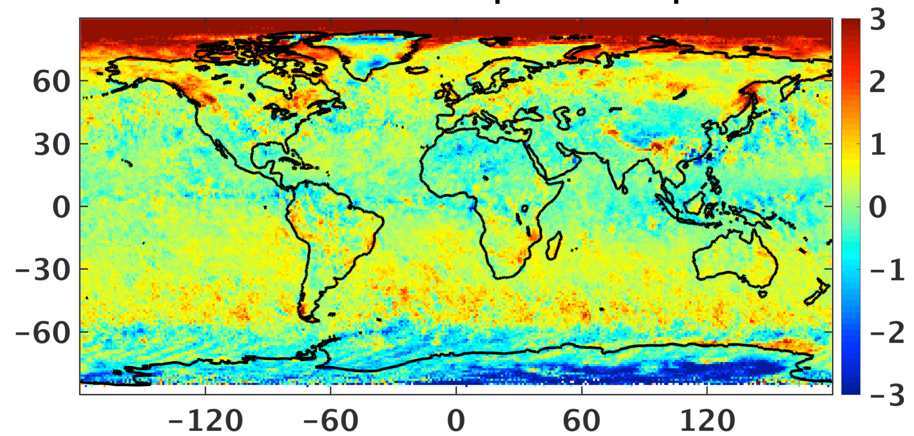


NPP-Aqua: April 2013

Cloud fraction



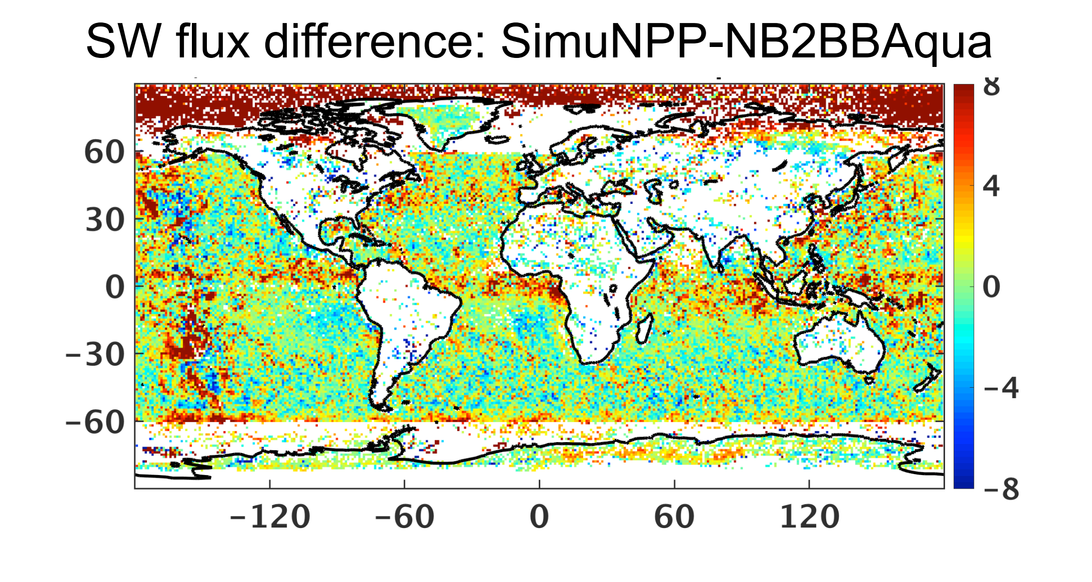
Cloud optical depth

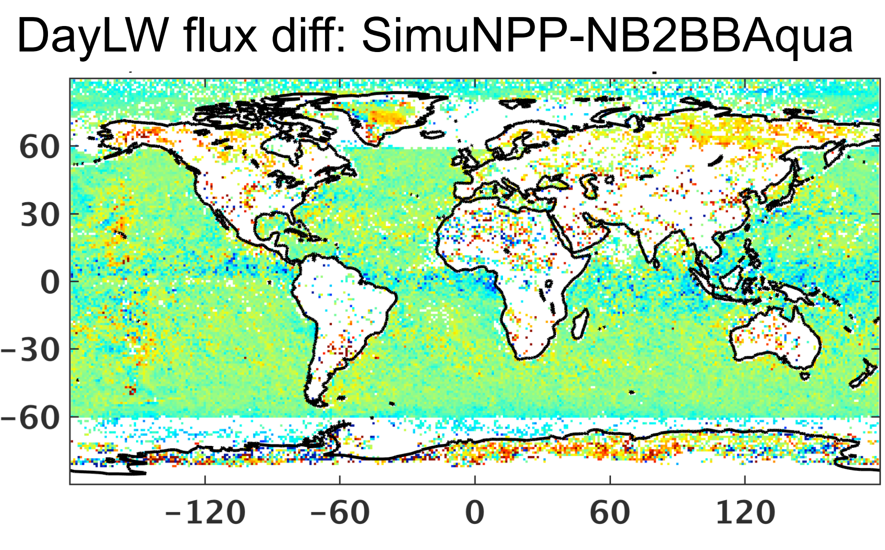


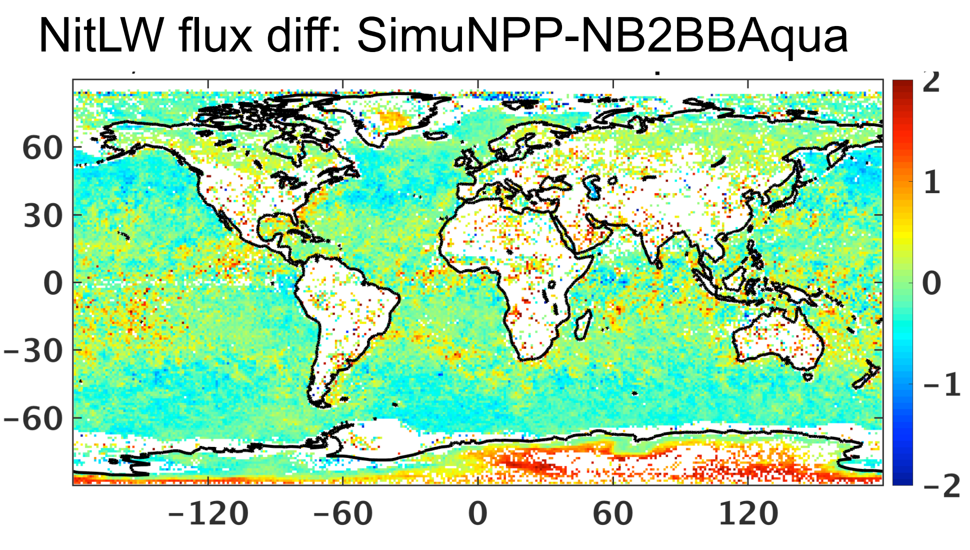
Adjust the simulated NPP cloud fraction and cloud optical depth

- The simulated NPP footprints are based upon Aqua data and the cloud properties used for simulated NPP and Aqua are almost identical
- Adjust the Aqua cloud fraction and cloud optical depth in simulated NPP footprints, so they are close to those of NPP retrievals
- Calculate the daily cloud fraction ratio (NPP/Aqua) using all footprints for each 1° by 1 ° grid box. Then apply this ratio to cloudy simulated NPP footprints to nudge the cloud fraction to be close to that of NPP.
- Similarly, calculate the daily cloud optical depth ratio (NPP/Aqua) using only cloudy footprints in each 1° by 1 ° grid box. Then apply this ratio to cloudy simulated NPP footprints to nudge the cloud optical depth to be close to that of NPP.

Flux errors due to footprint size and cloud property differences







Flux errors due to footprint size and cloud property differences

- Footprint size difference between CERES instruments on Aqua and on Suomi-NPP leads to:
  - Underestimation of global monthly mean SW flux by 0.7 Wm^{-2} and overestimation of global monthly mean LW flux by 0.2 Wm^{-2}.
  - The mean absolute errors for SW and LW are less than 1 Wm^{-2} .
  - Differences on regional scale are also small.
- Footprint size and cloud property difference between CERES instruments on Aqua and on Suomi-NPP lead to:
  - Overestimation of global monthly mean SW flux by 0.9 Wm^{-2} and an overestimation of global monthly mean LW flux by 0.1 Wm^{-2}.
  - However, the mean absolute errors are about 4 Wm^{-2} for SW flux and 0.7 Wm^{-2} for LW flux.
  - Regionally, SW flux error up to 20 Wm^{-2} and LW error up to 3 Wm^{-2} are observed over polar regions.